

Role of the Cluster Analysis in Logfacies and Depositional Environments Recognition from Well Log Response for Mishrif Formation in Southeast Iraq.

Jawad K. Radhy AlBahadily^{1*}, Medhat E. Nasser²

Department of geology, college of science, Baghdad University, Baghdad, Iraq.

*Corresponding Author Email: jawadkzm@gmail.com

Abstract—The recognition of depositional environments from well logs is based on the principle that well log responses are related to changes in thickness, texture, grain size and lithology along the well path. The variations in sedimentary rock response are due to reservoir heterogeneity. A similar set of log responses that characterizes a specific rock type and allows it to be distinguished from others, have defined an electrofacies. Cluster analysis includes a broad suite of techniques designed to find groups of similar items within a data set. Partitioning methods divide the data set into a number of groups predesignated by the user. Hierarchical cluster methods produce a hierarchy of clusters from small clusters of very similar items to large clusters that include more dissimilar items. Hierarchical methods usually produce a graphical output known as a dendrogram or tree that shows this hierarchical clustering structure. The method has tested on a 398.5 m thick interval of Carbonate deposits in a vertical well from Amara field, located in southeast Iraq. Modal data have collected from both core and cutting samples. Cluster analysis and electrofacies classification have performed using advance interpretation in Interactive Petrophysics software version 3.6. Carbonate microfacies and marine depositional environments studied for Mishrif Formation depended on the available thin sections though they were not enough to cover all the depositional environments of Mishrif Formation. Therefore, previous studies and well logs were also depended in this study. Correlation of determined logfacies with those defined from cores and cuttings is fundamental to check the reliability of used methods and to define a meaningful cut off level for wells from which no cores or cuttings are available.

Keywords—Cluster analysis, Mishrif Formation, Logfacies, Well Logs response,

I. INTRODUCTION

The identification of depositional environments from well logs is based on the principle that well log responses are related to changes in thickness, texture, grain size and lithology along the well path. The variations in sedimentary rock response are due to reservoir heterogeneity. The description of a rock in terms of its type, origin, and depositional environment is called a Lithofacies description. This can be done by direct observation of the rocks or inferred from analysis and interpretation of well log data. Determining lithofacies from well logs requires calibration to known rocks (cores, samples, or outcrops). Understanding the rock facies is the only way to reconstruct the paleogeography of a lithologic succession, rock sequence, which in turn provides clues as to a potential reservoir quality and lateral extent (Crain, d. g.).

The purpose of well log cluster analysis is to look for similarities/dissimilarities between data points in the multivariate space of logs, in order to group them into classes also called electrofacies (Euzen, T., Delamaide, E., Feuchtwanger, T., & Kingsmith, 2010).

An electrofacies is defined by a similar set of log responses that characterizes a specific rock type and allows it to be distinguished from others. Electrofacies are obviously influenced by geology and often can be assigned to one or another lithofacies, although the correspondence is not universal (Doveton, J. H., & Prensky, 1992).

Electrofacies are primarily observational in nature, and the classification procedure is based on three steps: principal component analysis, cluster analysis, and discriminant analysis. Principal component analysis is used to summarize the data and to reduce the dimensionality of the data without any significant loss of information. The method displays the data as a function of new variables, called principal components, that are simple linear combination of the well logs. The aim of cluster analysis is to classify the well-log data into groups that are internally homogeneous and externally isolated on the basis of a measure of similarity or dissimilarity between the groups. The clusters define electrofacies on the basis of the unique characteristics of well-log measurements reflecting minerals and lithofacies within the logged interval. Once the electrofacies are identified, we can use discriminant analysis, a multivariate statistical method, to assign an individual observation vector to one of the predefined electrofacies (Perez, Datta-Gupta, & Mishra, 2005).

II. BASIC CONCEPTS

Cluster analysis includes a broad suite of techniques designed to find groups of similar items within a data set. Partitioning methods divide the data set into a number of groups predesignated by the user. Hierarchical cluster methods produce a hierarchy of clusters from small clusters of very similar items to large clusters that include more dissimilar items. Hierarchical methods usually produce a graphical output known as a dendrogram or tree that shows this hierarchical clustering structure. Some hierarchical methods are divisive, that progressively divide the one large cluster comprising all of the data into two smaller clusters and repeat this process until all clusters have been divided. Other hierarchical methods are agglomerative and work in the opposite direction by first finding the clusters of the most similar items and progressively adding less similar items until all items have been included into a single large cluster. Cluster analysis can be run in the Q-mode in which clusters of samples are sought or in the R-mode, where clusters of variables are desired (Holland, 2006).

The clusters define electrofacies on the basis of the unique characteristics of well-log measurements reflecting minerals and lithofacies within the logged interval. Once the electrofacies are identified, we can use discriminant analysis, a multivariate statistical method, to assign an individual observation vector to one of the predefined electrofacies (Perez et al., 2005).

The Cluster Analysis module uses standard statistical routines to allow the user to cluster the data into groups to produce an electrical facies log. This log can then hopefully be used to correlate to geological facies (Senegy, 2008).

III. METHODOLOGY

The theory of Cluster Analysis is the module works in two stages. Firstly, the data is divided up into manageable data clusters. The number of clusters should be enough to cover all the different data ranges seen on the logs. 15 to 20 clusters would appear to be a reasonable number for most data sets. The second step, which is more manual, is to take these 15 to 20 clusters and group them into a manageable number of geological facies. This may involve reducing the data to 4 to 5 clusters.

(Stage-1 K-mean clustering) The first stage of Facies Clustering uses the K-mean statistical technique to cluster the data into a known entered number of clusters. For this to work an initial guess has to be made of the mean value of each cluster for each input log. The initial guess can affect the results and in order to get good results the initial values should cover the total range of the logs. K-mean clustering works by assigning each input data point to a cluster. The routine tries to minimize the within-cluster sums of squares of the difference between the data point and the cluster mean value. The routine works by calculating the sum of the squares difference for a data point and each cluster mean and assigning the point to the cluster with the minimum difference. Once all the data points have been assigned to the clusters the new mean values in each cluster are calculated. Using the new mean values the routines starts again re-assigning the data to the clusters. This loop continues until the mean values do not change between loops. These then become the results.

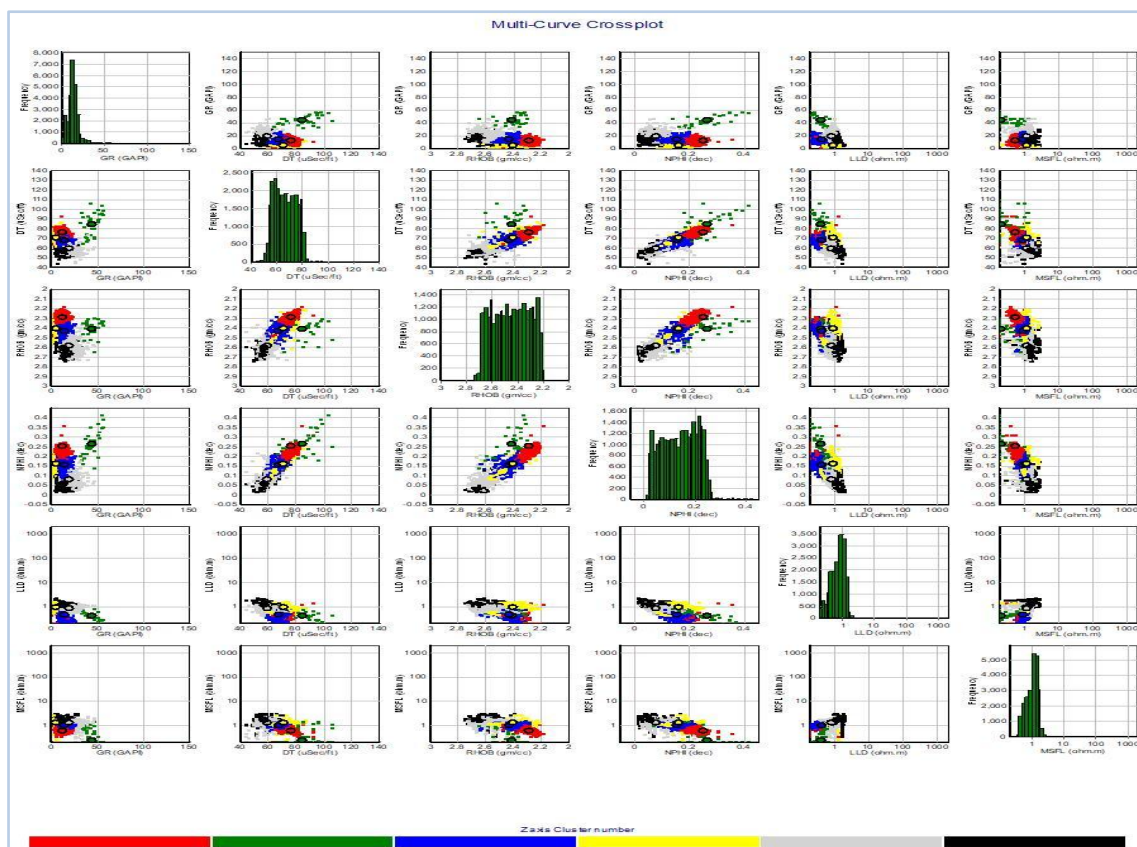


FIGURE (1): CROSSPLOTS AND HISTOGRAMS BETWEEN (RHOB, NPHI, DT, GR, LLD AND MSFL)AS GENERATED BY K-MEANS CLUSTER ANALYSIS FOR GROUPS OF MISHRIF FORMATION

(Stage-2 Cluster Consolidation) Cluster consolidation can be done completely manually by using the crossplot and log plot output to group data, or a hierarchical cluster technique can be used to group the data. Hierarchical clustering works by computing the distances between all clusters and then merging the two clusters closest together. The new cluster distance to all other clusters is then recomputed and the two closest clusters merged again. This process continues until you have only one cluster. The results can be plotted as a dendrogram, which IP displays. The dendrogram shows how the clusters were merged and the order they were merged (Senery, 2010).

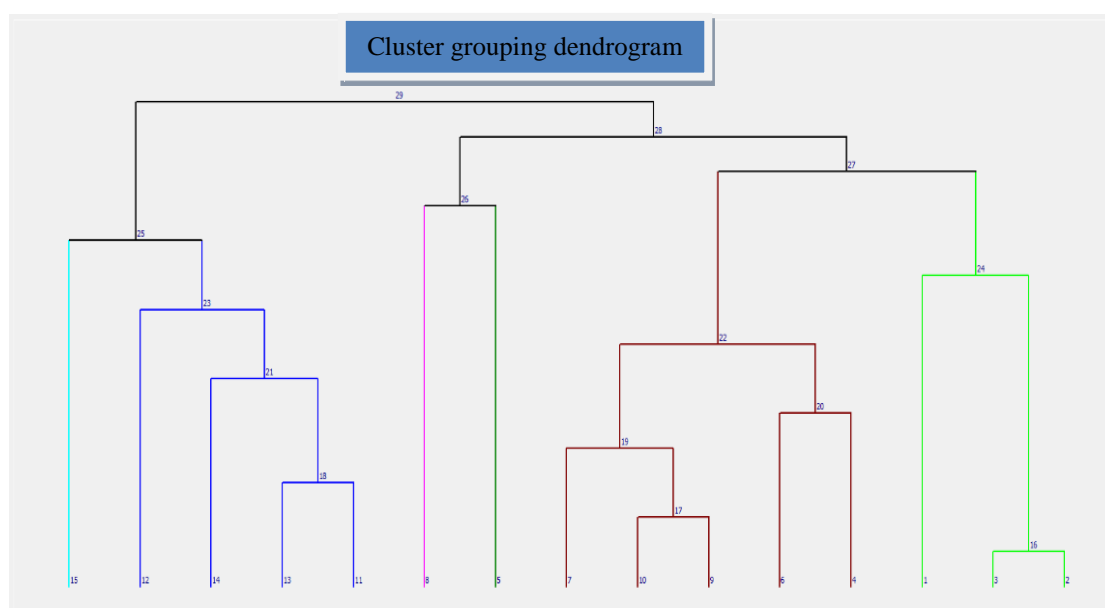


FIGURE (2): CLUSTER GROUPING DENDROGRAM OF MISHRIF FORMATION

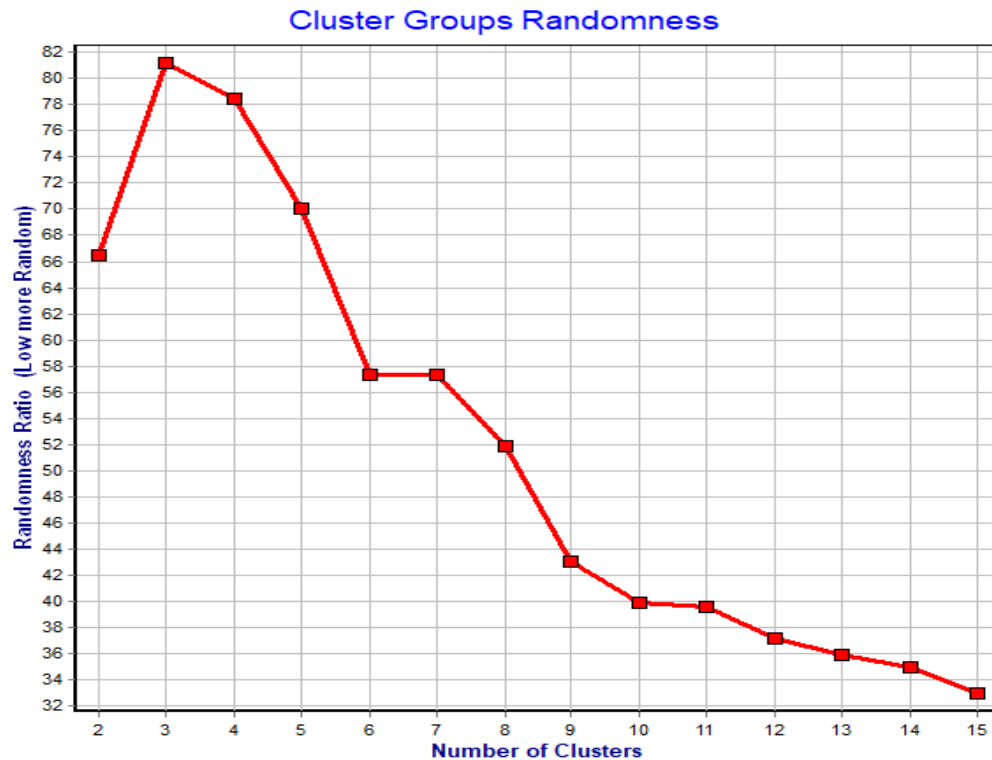
**FIGURE (3): CLUSTER GROUPS RANDOMNESS OF MISHRIF FORMATION**

TABLE 1
THE PROPERTIES FOR GROUPS OF CLUSTERS AND ENVIRONMENT

Zones	Clusters of group	Environment
MISHRIF	6	Lagoon
MA	4	Rudist Biostrome+ Shoal
BAR-2	3	Lagoon
MB11	2.3	Rudist Biostrome+ Shoal
BAR-3	3.4	Lagoon
MB12	3.2	Rudist Biostrome
BAR-4	4.2.3	Lagoon
MB13	2.3	Back Shoal
BAR-5	6	Basin
MB21	1.2	Slope
BAR-6	6.5.3	Basin
MC1	2.1.3	Slope
BAR-7	3.2	Basin
MC2	3.2.	Slope

IV. RESULTS AND DISCUSSIONS

The method has tested on a 398.5 m thick interval of Carbonate deposits in a vertical well from Amara field, located in southeast Iraq. Modal data have collected from both core and cutting samples. Cluster analysis and electrofacies classification have performed using advance interpretation in Interactive Petrophysics software version 3.6.

Recognition of Logfacies is a common practice in drilled wells where suitable well logs and core samples are available. Cluster analysis techniques such as hierarchical and k-means cluster analysis can be used for classifying well log data into discrete classes.

However, studying this part was made through two trends. The first trend includes the petrography and microfacies analysis of Mishrif Formation have been studied on the basis more than (120) thin sections of core samples and the previous microfacies studies for Mishrif Formation. The second trend includes the Mishrif depositional environments in studied wells depending on the available well logs utilizing cluster analysis technique.

4.1 Carbonate Microfacies and Depositional Environments

Carbonate microfacies and marine depositional environments studied for Mishrif Formation depended on the available thin sections though they were not enough to cover all the depositional environments of Mishrif Formation. Therefore, previous studies and well logs were also depended in this study.

4.2 Mishrif Facies Associations

The Mishrif Formation carbonates were classified following Dunham's (1962) classification (modified by Embry and Klovan, 1971) into mud- or grain-supported textural types. Each type consists of three principal microfacies, (Aqrawi, Thehni, Sherwani, & Kareem, 1998) as follows:

4.2.1 Mud-supported microfacies

4.2.1.1 Pelagic mudstone/wackestone

This microfacies occurs at various levels in Mishrif Formation, but was existing in the lower parts. Micrite is the main component, but planktonic foraminifera also occur in various proportions usually less than 50%. This microfacies dominates the underlying Rumaila Formation (Aqrawi, 1983; Aqrawi and Khaiwka, 1986 and 1989). Pelagic lime mudstone/wackestones are usually interpreted as outer-shelf or basinal deposits (Wilson, 1975).

4.2.1.2 Bioclastic wackestone

Bioclastic wackestones comprise one of the most common microfacies in the Mishrif Formation carbonates. Bioclasts (such as Praealveolinids, algae and echinoderms) comprise between 10 and 40% of the lithology, and limited pelagic foraminifera also occur. The microfacies is characteristic of shallow, open-marine environments (Flügel, 1982).

4.2.1.3 Wackestone/packstone

Wackestones/packstones are quite common in Mishrif formation. Benthic foraminifera (such as Miliolids and Textularia), sponge spicules, algae, small mollusc fragments and echinoderms occur in this microfacies in proportions up to about 50%. The microfacies is typical of lagoons (Flügel, 1982) or restricted subtidal zones with warm shallow waters and moderate circulation (Tucker, 1985).

4.2.2 Grain-supported microfacies

4.2.2.1 Peloidal packstone

This microfacies is principally composed of peloids of various sizes, many of which have an uncertain internal structure. In addition, benthic foraminifera, rudist fragments and ostracods also occur. The microfacies is common in the upper parts of the Mishrif Formation, and is interpreted to indicate shoals and subtidal zones.

4.2.2.2 Rudistid packstone/grainstone

This microfacies is characterised by a high content of rudist fragments, which are associated with other bioclasts such as algal debris, benthic foraminifera and peloids (in smaller proportions). It is one of the two principal reservoir facies of the Mishrif Formation. Rudist grainstones are interpreted to be a reef-bank or shoal deposit, and rudist packstones to be a back-reef deposit.

4.2.2.3 Rudstone

Rudstones are composed of rudist fragments, most of which are larger than sand-grade, in addition to coral fragments of a similar size. This microfacies is interpreted to be a fore-reef slope deposit (Wilson, 1975) . The rudstones and rudistid packstone/grainstones are generally over- and underlain by subtidal and outer-shelf facies, respectively, in the boreholes studied. These two microfacies are characterised by high primary and secondary porosities and permeabilities; together, they form the most important reservoir units in the Mishrif Formation throughout the Mesopotamian Basin (Aqrawi et al., 1998).

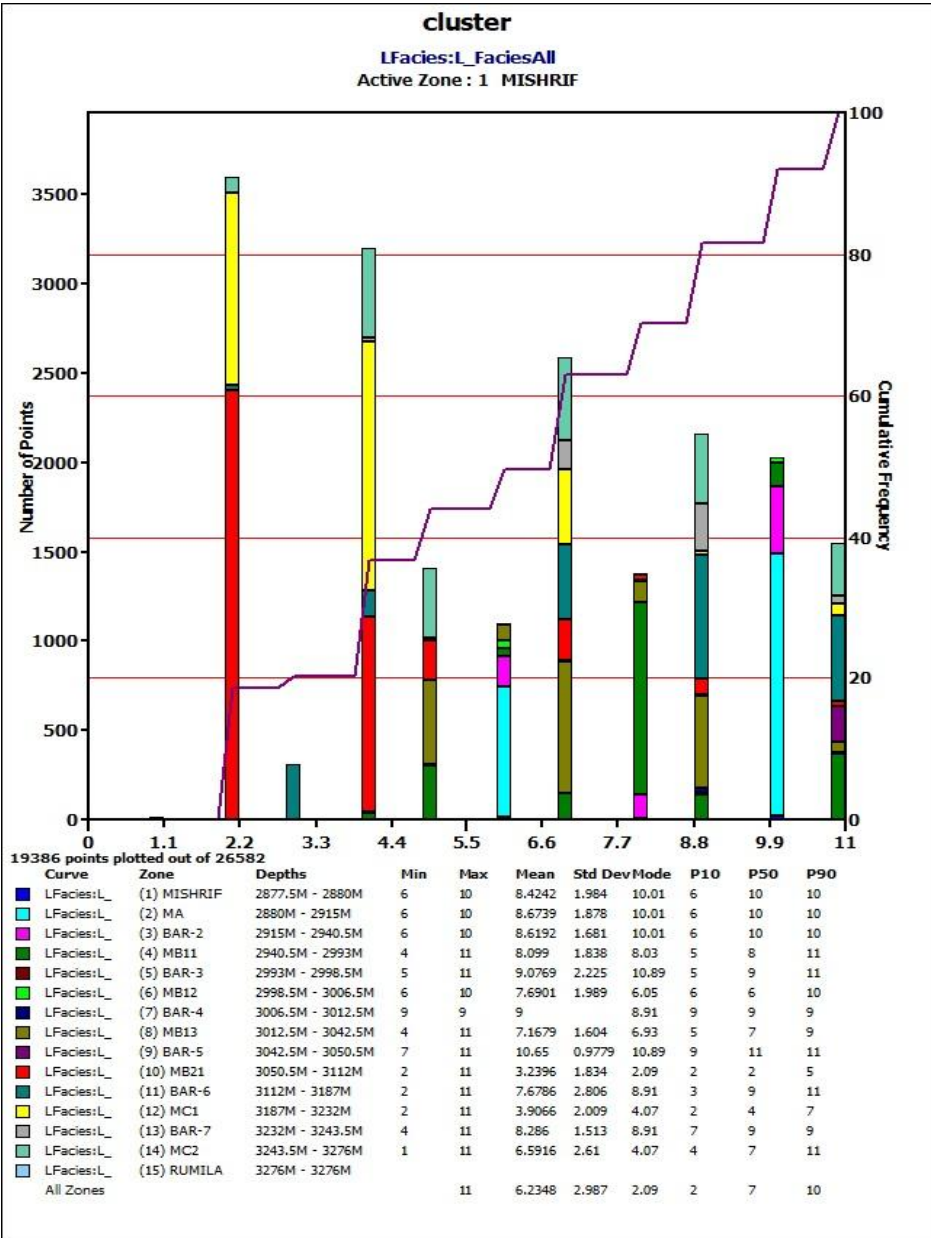


FIGURE (4): HISTOGRAM OF LOGFACIES FOR ZONES OF MISHRIF FORMATION

Mishrif platform carbonates throughout the southern Iraq and especially in southeast Iraq can be divided into the following facies associations (Figure 4):

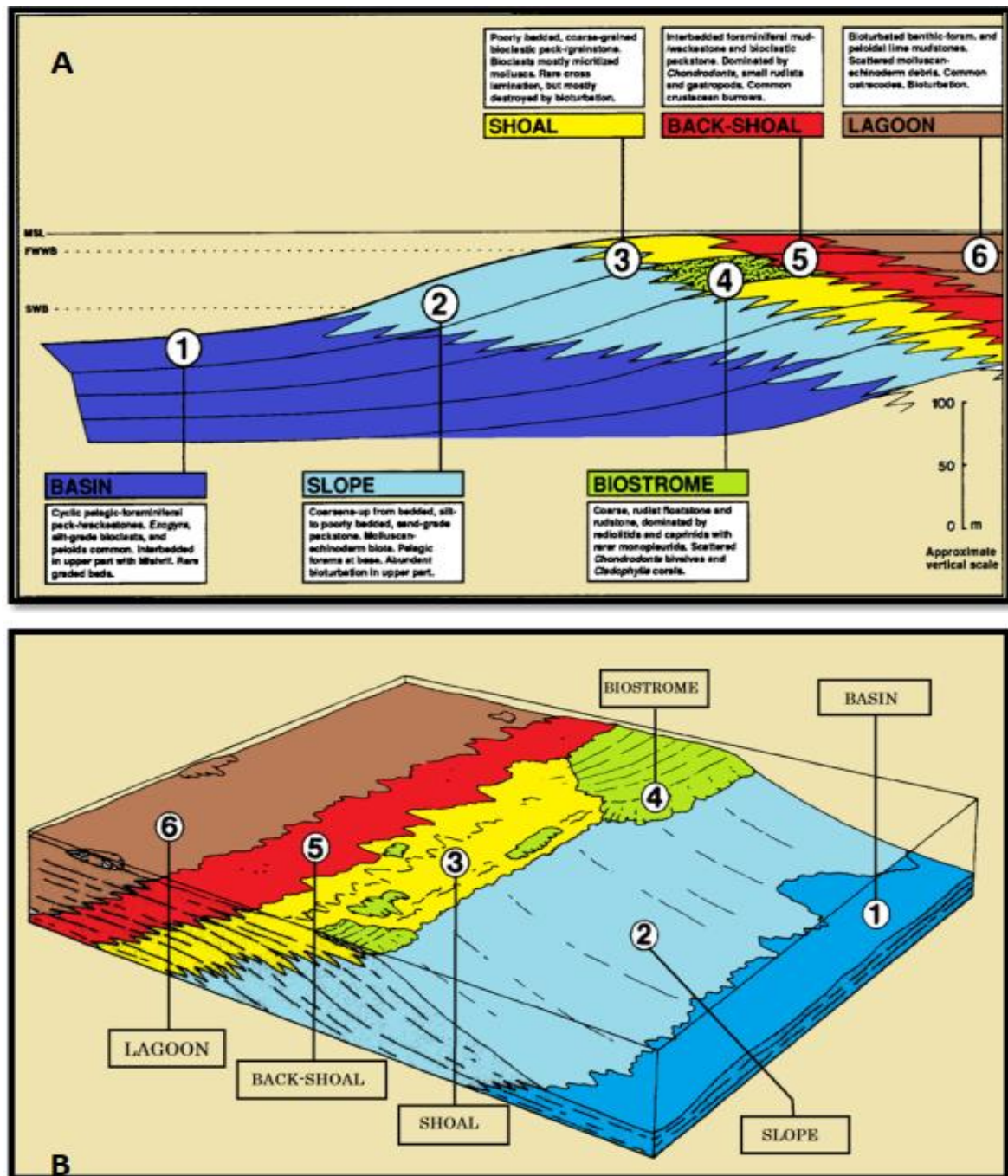


FIGURE (5): A-SCHEMATIC CROSS SECTION OF MISHRIF PLATFORM SHOWING THE ENVIRONMENTS OF DEPOSITION OF MICROFACIES ASSOCIATION. B-BLOCK DIAGRAM SHOWING DEPOSITIONAL ENVIRONMENTS OF MISHRIF FORMATION AND THE DISTRIBUTION OF MICROFACIES ASSOCIATIONS (CIRCLED NUMBERS). (FIGURES A & B ARE MODIFIED AFTER(BURCHETTE, 1993).

4.3 Mishrif Depositional Environments

4.3.1 Basin Environment

Basinal environment is simply the end of the marine environmental spectrum that began at the strandline and ended at the deepest part of that particular sedimentary basin (Figure 4). There is not even a rigid definition of basinal environment or

basinal facies. In fact, the greatest depth that exists in one basin may be the same measured depth as the shallow subtidal regime in another basin (Ahr, 2008).

4.3.2 Slope Environment

Slopes are commonly sites for upwelling, initiation of density or turbidity currents, and initiation of slumps, rock falls, and debris flows triggered by slope failures (Figure 4). Environmental processes on slopes are dominated by gravitational forces and pounding from waves. Upper slope zones in relatively shallow water may be subject to wind or storm waves, oceanic currents, and tides. Middle slope and base of slope zones are typically below fair - weather wave base, below the influence of surface currents, and relatively less influenced by tidal currents than the upper slope zone. Deeper parts of slope zones are sites where rocks and sediments swept off the slope by shallow - water processes come to rest (Ahr, 2008).

The succession, coarsening upward from basinal limestone to shallow marine packstone, reflects shallowing of the depositional environment in response to progradation of carbonate slope (Burchette, 1993).

4.3.3 Shoal Environment

Shoal forms a barrier that absorbs most of the wave energy from the open ocean (Nichols, 2009). This is the most widespread coarse-grained facies association of Mishrif Formation. The shoal association is composed of off-white, poorly sorted bioclastic packstone, grainstone, and rudstone. Bioclasts are predominantly molluscan, mostly rudistid. It represents the deposits of low energy shoals and banks along the platform margin (Burchette, 1993).

4.3.4 Rudist Biostrome Environment

This facies association represents the most important reservoir rock in Mishrif Formation. The diverse fauna, distribution, and context of this facies at the top of a coarsening upward succession all indicate an origin as biostromes within the prograding margin (Burchette, 1993).

4.3.5 Back Shoal Environment

Thin to medium-bedded, fine to very coarse-grained bioclastic packstone, wackestone, and grainstone characterize this association. The sediments are more varied, indurated, and stylolitized than other coarse facies. These deposits represent a zone of sediment mixing between shoal and interior lagoon. They overlie the coarsening upward succession and are interbedded in several-meter-thick intervals with lagoonal sediments (Burchette, 1993).

4.3.6 Lagoon Environment

Shallow elongate body of water between the mainland and a barrier island where circulation is commonly restricted and access to marine waters is only through inlets (Hughes, 1999). The lagoon association is characterized by indistinctly bedded benthonic foraminiferal and peloidal lime mudstone and wackestone. Molluscan (including rudist) debris, echinoderm, and ostracodes are locally important (Burchette, 1993).

The figure (1) shows Crossplots and histograms between (RHOB,NPHI,DT,GR,LLD and MSFL) as generated by k-means cluster analysis for groups of Mishrif Formation. The properties of these groups of logfacies have presented in Table 1. The figure(2) of dendrogram shows the Mishrif Formation has divided into 15 clusters and then created six groups of Logfacies, based on input data (RHOB,NPHI,DT,GR,LLD and MSFL) that utilized to build clusters. The results of "Cluster Means" have presented in Table (2) that shows the mean values plus other statistics of used data for each cluster (15 clusters). After classification of used data into 15 clusters, the groups of logfacies have created from these clusters. The Mishrif Formation has divided into six groups. Each group of logfacies has characterized to determine reservoir properties and each group may be containing one cluster or more than one cluster. Depending cluster groups have recognition environments own Mishrif formation that shows in figure (6).

TABLE 2
THE RESULTS OF “CLUSTER MEANS” PLUS OTHER STATISTICS OF USED DATA FOR EACH CLUSTER

K-Mean Clustering Results														
Cluster	#	Cluster	RHOB		NPHI		DT		GR		LLD		MSFL	
#	Points	Spread	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
0	863	0.5285	0.35413	0.00535	-0.64666	0.02324	1.8958	0.01248	0.79103	0.08191	-0.06746	0.07126	0.50984	0.08867
1	2841	0.7332	0.35496	0.00849	-0.61898	0.04001	1.8975	0.02257	1.193	0.1611	-0.01268	0.1367	0.48738	0.1577
2	3006	0.5053	0.36542	0.00508	-0.69029	0.03384	1.8691	0.01151	1.1211	0.0746	0.09248	0.08215	0.67196	0.07628
3	1392	0.8542	0.37293	0.00863	-0.71496	0.05205	1.861	0.02549	0.9327	0.08081	0.56225	0.2242	0.94635	0.1842
4	868	0.9621	0.36789	0.01118	-0.71437	0.0496	1.8778	0.02252	0.58838	0.09861	0.89645	0.202	1.1223	0.244
5	2540	0.6502	0.38125	0.0071	-0.77627	0.0497	1.8411	0.01493	1.1551	0.08541	0.33415	0.113	0.85991	0.1148
6	1369	0.8896	0.38716	0.00909	-0.8296	0.05832	1.8286	0.022	1.1391	0.1034	0.77388	0.1888	1.2675	0.1886
7	1505	1.054	0.3881	0.00961	-0.84366	0.07606	1.8279	0.02742	0.68786	0.09804	1.2183	0.1988	1.5468	0.273
8	2085	0.7369	0.40306	0.00845	-0.94258	0.1017	1.7939	0.01734	1.1063	0.06373	0.56012	0.1152	1.1127	0.132
9	1121	0.9448	0.39313	0.00906	-0.88176	0.08404	1.8032	0.03249	1.3128	0.09857	0.55189	0.1346	0.97268	0.253
10	1902	0.8349	0.40623	0.00781	-1.0181	0.07272	1.7834	0.02132	1.2926	0.09426	0.82135	0.1637	1.3836	0.1577
11	1282	1.069	0.40772	0.00669	-1.1102	0.1122	1.7706	0.025	1.0659	0.1332	1.1813	0.1651	1.7578	0.279
12	2050	0.7118	0.41812	0.00546	-1.2165	0.09504	1.7649	0.0154	1.1552	0.07663	0.87929	0.1545	1.2424	0.148
13	1280	0.9076	0.42119	0.00678	-1.3004	0.1209	1.7503	0.02054	1.3899	0.09345	1.0236	0.1413	1.3301	0.2084
14	2061	0.8811	0.42384	0.00513	-1.5124	0.1085	1.7413	0.01735	1.1805	0.1283	1.2795	0.1933	1.549	0.2124

Output Curves Cluster Values		
All Cluster		User set 1
Crv Name	L FaciesAll	L Facies
Cluster	Value	Value
0	1	1
1	2	1
2	3	1
3	4	2
4	5	3
5	6	2
6	7	2
7	8	4
8	9	2
9	10	2
10	11	5
11	12	5
12	13	5
13	14	5
14	15	6

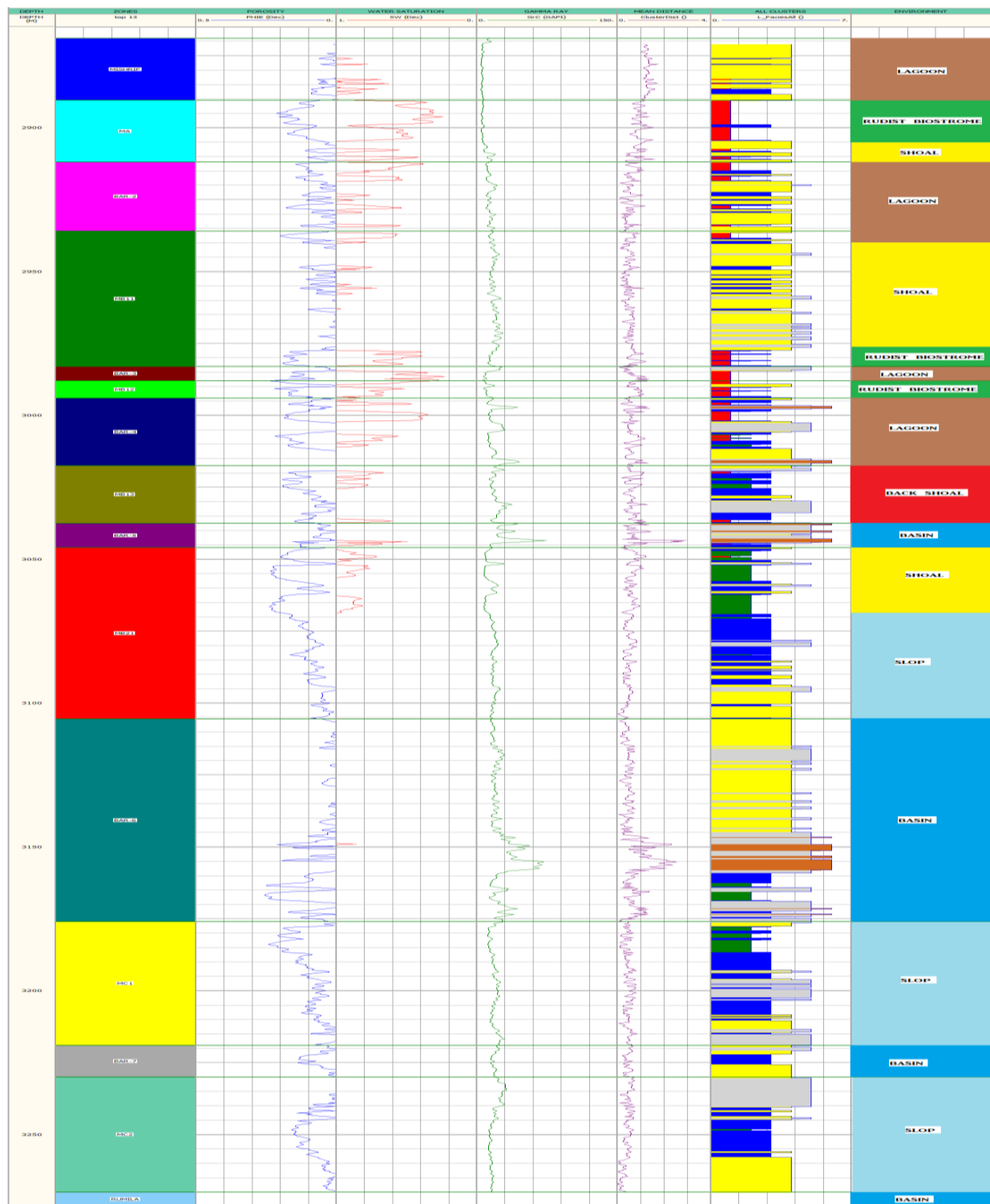


FIGURE (6): DEPOSITIONAL ENVIRONMENTS COLUMN OF MISHRIF FORMATION

V. CONCLUSION AND RECOMMENDATION

The function of multivariate cluster analysis based on response well logs determination has documented in this study by comparing with thin section examination. Based on different cutoff levels, a desirable number of logfacies for any given formation has achieved. Correlation of determined logfacies with those defined from cores and cuttings is fundamental to check the reliability of used methods and to define a meaningful cut off level for wells from which no cores or cuttings are available. The pliability of this technique in using the different combination of logs effective in the recognize logfacies and environment.

REFERENCES

- [1] Ahr, W. M. (2008). *Geology of Carbonate Reservoirs: The Identification, Description, and Characterization of Hydrocarbon Reservoirs in Carbonate Rocks. Geology of Carbonate Reservoirs: The Identification, Description, and Characterization of Hydrocarbon Reservoirs in Carbonate Rocks.* <https://doi.org/10.1002/9780470370650>
- [2] Aqrabi, A. A. M., Tehni, G. A., Sherwani, G. H., & Kareem, B. M. A. (1998). Mid-cretaceous rudist-bearing carbonates of the Mishrif formation: An important reservoir sequence in the Mesopotamian Basin, Iraq. *Journal of Petroleum Geology*, 21(1), 57–82. <https://doi.org/10.1111/j.1747-5457.1998.tb00646.x>
- [3] Burchette, T. P. (1993). Mishrif Formation (Cenomanian-Turonian), Southern Arabian Gulf: Carbonate Platform Growth Along a Cratonic Basin Margin, 2.
- [4] Crain, E. R. (Ross). (d. g.). Crain Petrophysics Handbook. Berreskuratua -(e)tik <https://www.spec2000.net/21-strat1.htm>
- [5] Doveton, J. H., & Prensky, S. E. (1992). Geological applications of wireline logs: a synopsis of developments and trends. *The Log Analyst*, 286–303.
- [6] Euzen, T., Delamaide, E., Feuchtwanger, T., & Kingsmith, K. D. (2010). Well Log Cluster Analysis: An Innovative Tool for Unconventional Exploration. *Society of Petroleum Engineers*. <https://doi.org/10.2118/137822-MS>
- [7] Holland, S. M. (2006). Cluster analysis, (January), 7. <https://doi.org/http://dx.doi.org/10.4135/9781412983648>
- [8] Hughes, B. (1999). *Petroleum Geology.Science (New York, N.Y.)*.
- [9] Nichols, G. (2009). *Sedimentology and Stratigraphy*. Blackwell.
- [10] Perez, H., Datta-Gupta, A., & Mishra, S. (2005). The Role of Electrofacies, Lithofacies, and Hydraulic Flow Units in Permeability Predictions From Well Logs: A Comparative Analysis Using Classification Trees. *SPE Reservoir Evaluation & Engineering*, 8(2), 5–8. <https://doi.org/10.2118/84301-PA>
- [11] Senergy. (2008). *Interactive Petrophysics Users Manual*.
- [12] Senergy. (2010). *Interactive Petrophysics V3.6 Online Help Interactive*.
- [13] Wilson, J. L. (1975). *Carbonate facies in geologic history*. Springer Science & Business Media.